Chronostratigraphic Hydrocarbon Plays and Depositional Styles in the Northern Gulf of Mexico

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Introduction

Currently, successful exploration for hydrocarbons in the Gulf of Mexico requires organizing information on hydrocarbon-distribution patterns and associated geologic and engineering parameters. To aid this effort, The University of Texas at Austin Bureau of Economic Geology, the U.S. Department of Interior Minerals Management Service, the Louisiana State University Basin Research Institute, and the Geological Survey of Alabama are developing an atlas series for the offshore northern Gulf of Mexico. The principal goal of the atlas series is to produce two atlases of hydrocarbon plays—one atlas of Miocene and older reservoirs and one atlas of Plio-Pleistocene reservoirs. By integrating data from gas and oil reservoirs with large-scale patterns of basin fill and geologic age, approximately 120 plays have been identified in the State and Federal part of the northern Gulf of Mexico (Fig. 1). Seni et al. (1994) described the play identification methodology and provided examples from lower Miocene plays from Texas State waters. For additional reports on aspects of the atlas series, see Lore and Batchelder (1995), Hunt and Burgess (1995), and Peterson and Cooke (1995) in this volume.

This report examines the influence of depositional style on the distribution of hydrocarbon resources and plays in the Gulf of Mexico. Several play-average parameters, such as porosity and reservoir depth, will illustrate how play-average values for various parameters can vary significantly as a function of depositional style. Depositional styles encompass the large-scale patterns of basin fill in the northern Gulf of Mexico and provide a basis for predicting the trends in sandstone quality and reservoir distribution. Three depositional styles used as primary defining attributes of plays in the offshore Gulf of Mexico are transgression (retrogradation), aggradation, and progradation (Fig. 2). Submarine fans were also identified as a primary defining attribute of plays. Although submarine fans are not confined to a single depositional style, they are identified uniquely because they compose an important depositional class of reservoirs on the slope and basinward of the modern shelf edge. Depositional styles were identified by using spontaneous potential (SP) log patterns, as well as water depth, paleoecological zones, seismic data, and structure (Seni et al., 1994).

Hydrocarbon Distribution

Age

Hydrocarbons in the northern Gulf of Mexico are unevenly distributed in terms of location, age of reservoir, and depositional style. Recoverable in-place hydrocarbons in the Federal OCS are hosted by Pleistocene plays (40 percent), Miocene plays (39 percent), Pliocene plays (20 percent), and Mesozoic plays (1 percent). Oligocene plays in Texas State offshore waters host less than 1 percent of the recoverable in-place hydrocarbons. When subdivided by chronozone, recoverable in-place hydrocarbons are concentrated in lower Pleistocene (7.53 billion boe), upper Miocene-UM3 (4.46 billion boe), and upper Pliocene (3.84 billion boe) (Fig. 3). Both cumulative production and reserves tend to closely track recoverable in-place hydrocarbons. One exception is the Mesozoic chronozone, where large gas reserves occur in the Jurassic Norphlet play. As a result of the recent discovery history of this play, however, cumulative production is small.

When separated into their oil and gas components, these same categories of resources reveal some interesting patterns (Fig. 4a, 4b). Oil resources are tightly grouped by age between the uppermost upper Miocene and lower Pleistocene chronozones (Fig. 4a). Oil resources are conspicuous in their relative underrepresentation in lower Miocene and older reservoirs. In contrast to the temporally restricted distribution of oil reservoirs, gas resources are broadly distributed in reservoirs ranging in age from Jurassic to upper Pleistocene (Fig. 4b). The lower Pleistocene chronozone contains the greatest abundance of both oil and gas resources.

In the Federal OCS, lower Miocene and older reservoirs generally occur below 3,050 m (10,000 ft). Heat and pressure favor the generation and accumulation of gas in these deeper reservoirs. The abundance of both gas and oil in thermally immature Pleistocene sediments indicates significant vertical migration from deeper sources.

Depositional Style

Location

The middle Pleistocene chronozone is a moderately productive chronozone that we will use to illustrate the relationship between the spatial distribution of plays and associated structural features. The production of the middle Pleistocene chronozone extends from the South Addition of High Island Area on the west to the Mississippi Delta on the east and from Louisiana State waters on the updip margin to beyond the shelf margin on the downdip margin (Fig. 5). The spatial separation of aggradational, progradational, and submarine-fan plays is one of the most obvious characteristics of the four middle Pleistocene plays. The aggradational play comprises separate, relatively small enclosures of reservoirs on the inner shelf. Enclosures represent the polygonal outline of a single field or a related group of fields that include reservoirs in that play and exclude fields that do not contain reservoirs in that play. The progradational play overlaps the aggradational play locally but generally forms a more continuous outline of reservoirs downdip of most aggradational reservoirs. Seismic and structural data reveal that the progradational play is located along the middle Pleistocene shelf margin. The submarine-fan play consists of two groups of disaggregated enclosures of reservoirs. The submarine-fan play is consistently located downdip of progradational reservoirs.

The center of the productive area of middle Pleistocene plays, extending from Eugene Island Area on the west to Grand Isle Area on the east, reveals how salt structural features have affected the pattern of play distribution (Fig. 6). Aggradational plays are preferentially located over isolated salt diapirs along the inner shelf. The isolated and relatively small size of the aggradational play outlines are controlled by the location and size of salt uplifts. In contrast, although some progradational play enclosures are located over salt structures, most of the progradational plays extend in a broad band within a series of large shelf-margin basins between the updip salt diapirs and the larger salt massifs that populate the middle Pleistocene slope. The submarine-fan play comprises dip-oriented outlines between the large salt massifs along sediment-dispersal pathways. The play-distribution pattern thus provides useful clues on the nature and location of sediment feeders, shelf margin location, and salt evolution history.

Hydrocarbon Resources

Recoverable In Place

Recoverable in-place hydrocarbons in the Federal OCS are concentrated in progradational plays (60 percent), submarine-fan plays (19 percent), aggradational plays (15 percent), retrogradational plays (5 percent), and combination plays (1 percent) (Fig. 7). The dominance of progradational style plays in hosting recoverable hydrocarbons is also reflected in individual chronozones (Fig. 8). The progradational depositional style is the overwhelmingly dominant hydrocarbon-bearing style from the middle Miocene to the Plio-Pleistocene for the larger chronozones (containing greater than 1 billion barrels of oil equivalent [boe]). The greatest amount of hydrocarbon resources in a single chronozone and depositional style is contained in the progradational style of the lower Pleistocene. Several of the weakly endowed chronozones older than the middle Miocene have recoverable hydrocarbons sequestered in various depositional styles. The oldest lower Miocene chronozone (LM1) has the most hydrocarbons in the submarine-fan depositional style. The Jurassic chronozone is dominated by an aggradational depositional style.

Recoverable in-place oil resources are concentrated in progradational style plays for virtually all chronozones hosting major hydrocarbon reserves (Fig. 9a). Oil resources in submarine-fan plays are concentrated in upper Pliocene and lower Pleistocene chronozones but are widely distributed in chronozones ranging from middle Miocene to upper Pleistocene. Aggradational plays host important oil resources in the upper Miocene (UM3), lower Pliocene, and lower Pleistocene chronozones. Recoverable in-place gas resources are widely distributed in progradational style plays ranging from lower Miocene to upper Pleistocene (Fig. 9b). Gas resources in submarine-fan plays are concentrated in upper Pliocene, lower Pleistocene, and oldest lower Miocene (LM1). Aggradational plays host significant but relatively modest gas resources in the Jurassic and upper Miocene through upper Pleistocene chronozones.

As a result of the progressive outbuilding of the continental shelf, the progradational depositional style contains highly favorable packages of alternating reservoir-quality sandstones interbedded with thick sealing shales. An extensional structural style comprising listric growth faults and rollover anticlines is associated with the progradational style of deposition. Diapiric salt, another favorable structural style, is spatially associated with progradational depositional style because rapid deposition along continental margins promotes diapiric growth and possibly enhances fluid migration into progradational sandstone reservoirs. Such trap styles combine with favorable association of multiple reservoir-quality sandstones and seals to enrich progradational facies. Further work is needed to quantify the hydrocarbon richness factor of progradational style plays and to examine that relationship with hydrocarbon type and source rock.

Reserves

The ranking of reserves in each depositional style is the same as their ranking for producible in-place hydrocarbon resources (Fig. 10). Progradational style remains dominant, containing 47 percent of total reserves. However, this represents a decline of 22 percent when compared with the percentage of producible in-place resources in progradational plays. In contrast, reserves in submarine-fan plays (32 percent) represent a 68 percent increase when compared with the percentage of producible in-place resources in submarine-fan plays. This relative shift of reserves from progradational plays to submarine-fan plays is evident for both oil and gas (Fig. 11a, 11b). In fact, a greater percentage of oil reserves remains in submarine-fan plays (44 percent) than in progradational plays (43 percent) (Fig. 11a). This transposition is largely a measure of the shift in exploration focus from the maturely explored shelf, where progradational plays have historically dominated, to deeper reservoir targets on the shelf and in deep-water tracts seaward of the shelf margin. The deeper tracts are where submarine fans are the primary depositional environment containing reservoir-quality sandstones.

Play-Average Attributes

The influence of depositional style on a range of engineering and geologic parameters is evident when the values of the parameters for all reservoirs are averaged by play or even by chronozone. For example, porosity for all plays in chronozones generally increases from the Jurassic to upper Pleistocene (Fig. 12). When broken down by depositional style, porosity varies significantly (Fig. 13). The average porosity of all submarine-fan plays is significantly lower

(26 percent) than the average of progradational (29 percent), retrogradational (28 percent), and aggradational (28 percent) plays. Together with depositional style, reservoir depth is a significant influence on reservoir porosity. Typically, the spread in play-average depth for each depositional style within a single chronozone ranges from 1,220 to 3,050 m (4,000 to 10,000 ft) (Fig. 14). Thus, the low play-average porosity of submarine-fan plays is explained in part by the significantly deeper average depth of submarine-fan reservoirs when compared with plays within the same chronozone.

Conclusions

The gas and oil atlas series will aid the exploration for new reserves in the Gulf of Mexico by providing a critical compilation of reservoir engineering and geologic data within a play framework. When incorporating robust predictors of trends in reservoir quality, such as depositional style, regional play analysis is particularly suited to redevelopment in mature areas of the basin, as well as in frontier areas. The substitution of play-average values for reservoirs that do not have such individual statistics is supported by common occurrence of statistically significant variations between plays and chronozones. Useful clues on the nature and location of sediment feeders, shelf-margin location, timing of salt diapirism and faulting, and fluid-migration history can be gleaned from careful analysis of the location and spatial patterns of plays.

Acknowledgments

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SYSTEM	SERIES	ATLAS CHRONO-ZONE	CHRONO-ZONES	BIOCHRONOZONES
QUATERNARY	Pleistocene	UPL	UPL-4	Sangamon fauna
			UPL-3	*Trimosina* A 1st
			UPL-2	*Trimosina* A 2nd
			UPL-1	*Hyalinea* B/*Trimosina* B
		MPL	MPL-2	*Angulogerina* B 1st
			MPL-1	*Angulogerina* B 2nd
		LPL	LPL-2	*Lenticulina* 1
			LPL-1	*Valvulineria* H
TERTIARY	Plio-cene	UP	UP	*Buliminella* 1
		LP	LP	*Textularia* X
	Miocene	UM3	UM-3	*Robulus* E/*Bigenerina* A
			UM-2	*Cristellaria* K
		UM1	UM-1	*Discorbis* 12
		MM9	MM-9	*Bigenerina* 2
			MM-8	*Textularia* W
		MM7	MM-7	*Bigenerina humblei*
			MM-6	*Cristellaria* I
			MM-5	*Cibicides opima*
		MM4	MM-4	*Amphistegina* B
			MM-3	*Robulus* 43
			MM-2	*Cristellaria* 54/*Eponides* 14
			MM-1	*Gyroidina* K
		LM4	LM-4	*Discorbis* B
			LM-3	*Marginulina ascensionensis*
		LM2	LM-2	*Siphonina davisi*
		LM1	LM-1	*Lenticulina hanseni*
	Olig-ocene	OL1	Oligocene Frio–Anahuac	*Bolivina perca*
CRE-TACEOUS		LK		
JURASSIC		JUR		

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Figure 1. Chronostratigraphic subdivisions and biostratigraphic zones used for the Gulf of Mexico. Modified from Reed et al. (1987)

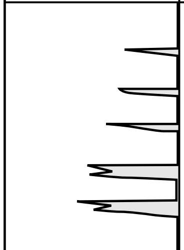
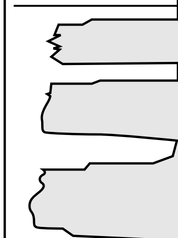
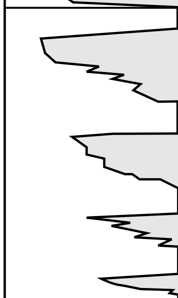
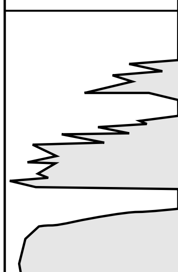
SP LOG SHAPE	DEPOSITIONAL STYLE/FACIES	CHARACTER
	RETROGRA-DATIONAL	Commonly upward-fining log character, rarely upward-coarsening; thin sandstone bodies, upward-thickening retrogradational package of sandstone bodies separated by thicker mudstones
	AGGRA-DATIONAL	Thick, blocky to upward-fining log character; stacked sandstone bodies separated by thinner mudstones
	PROGRA-DATIONAL	Commonly upward-coarsening log character, rarely upward-fining; thin to thick sandstone bodies; upward-thickening, progradational package of sandstone bodies separated by subequally thick mudstones
	DEEP-SEA FAN	Variable sandstone body thickness patterns; includes thick to thin, blocky to upward-fining log character, sharp-based sandstones; also, serrated, thin to thick sandstones; thick mud-stone at top; singular or stacked package of sandstone bodies; commonly upward-fining package

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Figure 2. Sand-body characteristics and idealized SP log shapes representing depositional styles

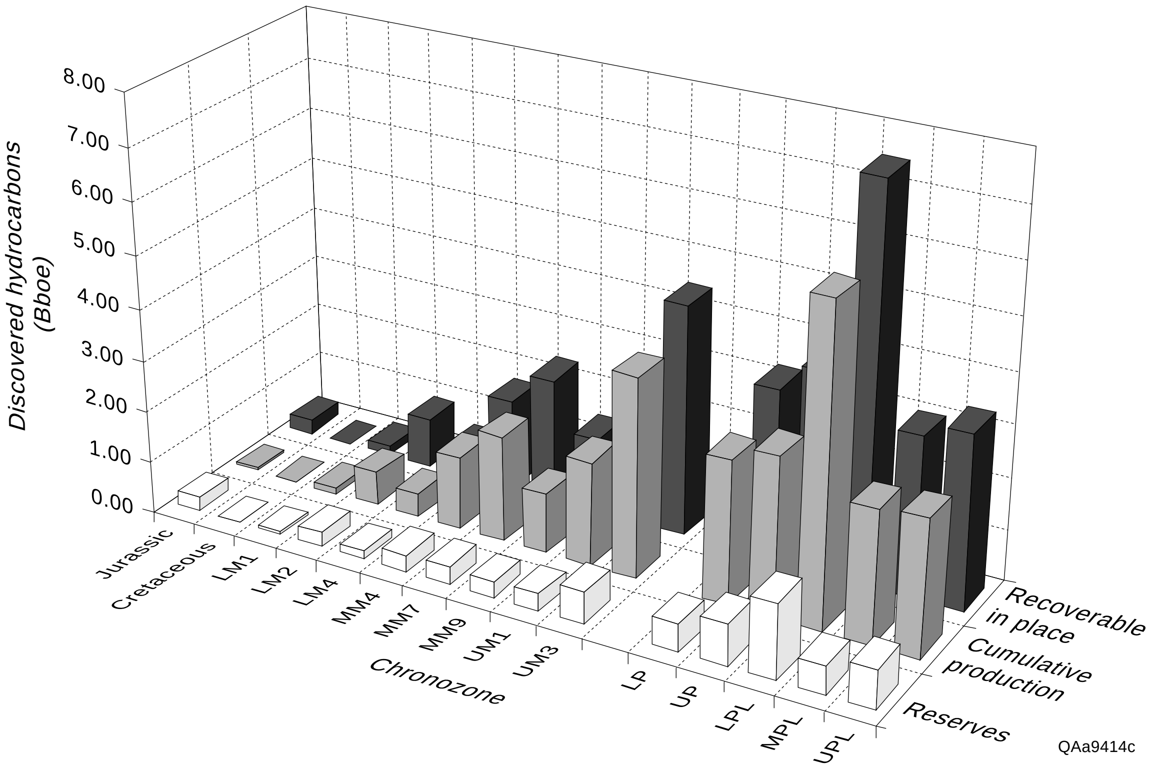


Figure 3. Discovered hydrocarbons (billion barrels of oil equivalent [boe]) in the Federal OCS. Chart illustrates recoverable in-place hydrocarbons, cumulative production, and reserves for each chronozone.

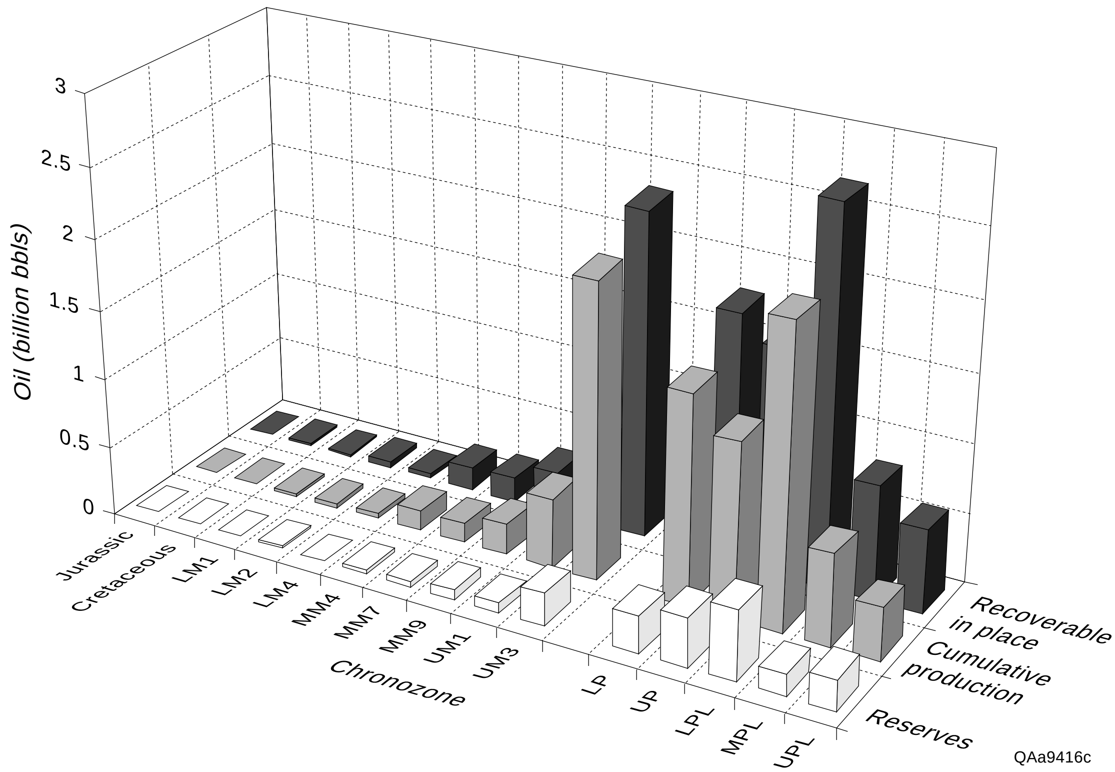


Figure 4a. Discovered oil (billion barrels) in the Federal OCS. Chart illustrates recoverable in-place hydrocarbons, cumulative production, and reserves for each chronozone.

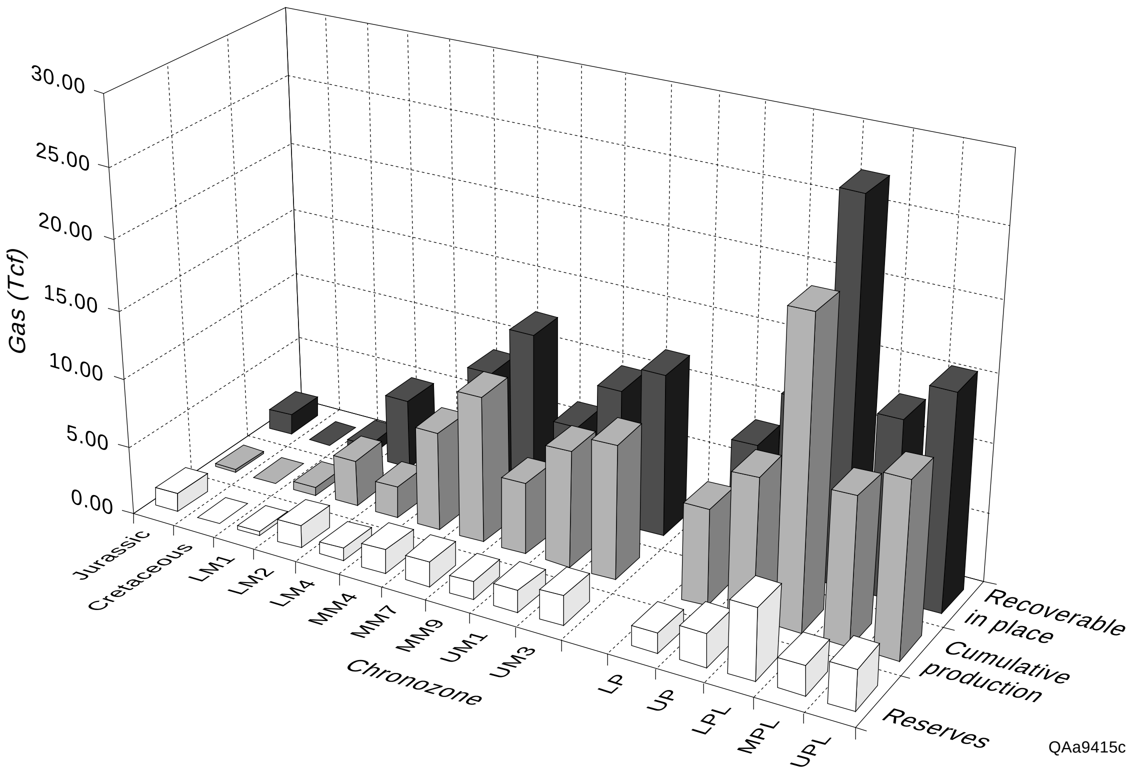


Figure 4b. Discovered gas (trillion cubic feet) in the Federal OCS. Chart illustrates recoverable in-place hydrocarbons, cumulative production, and reserves for each chronozone.

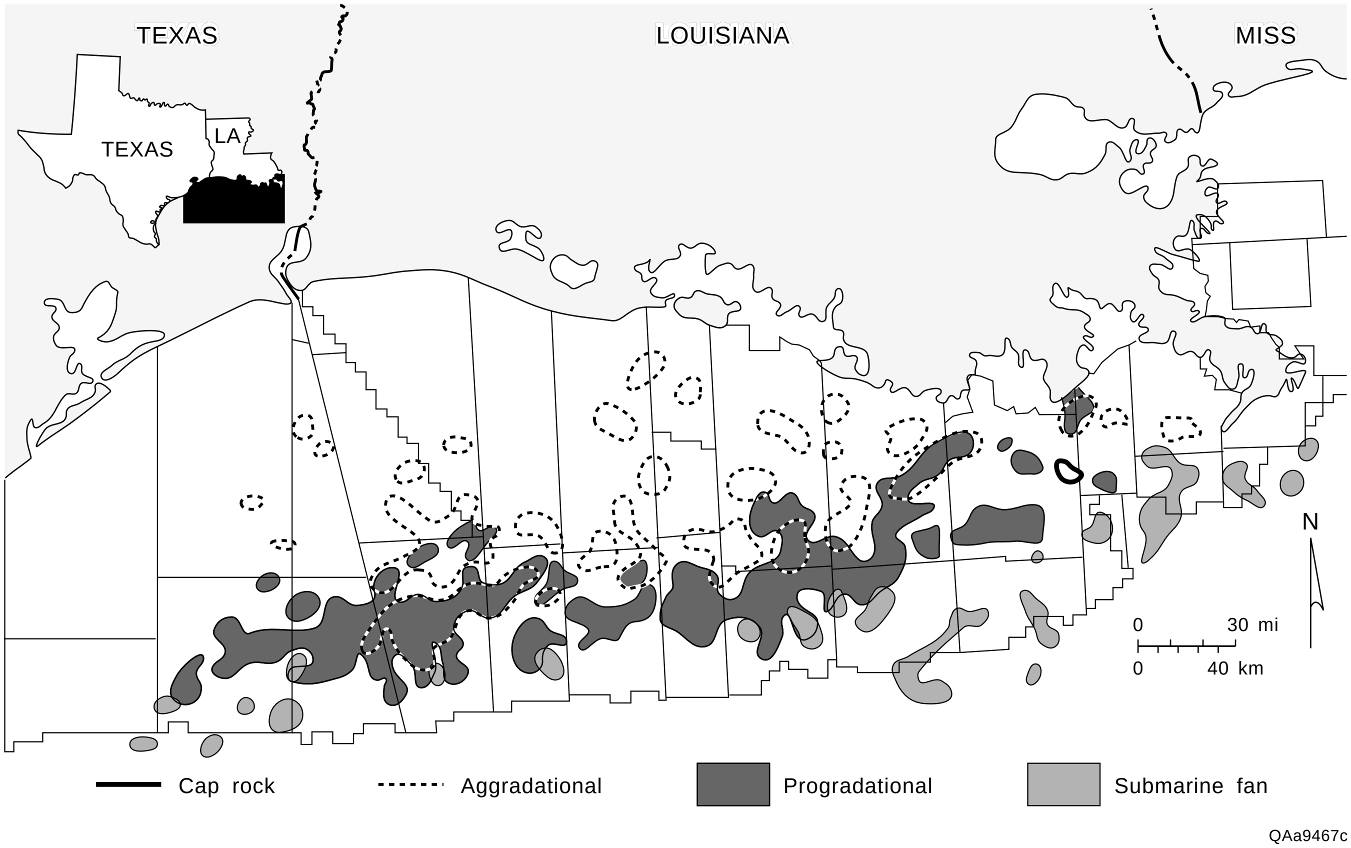


Figure 5. Map showing outline of plays for middle Pleistocene chronozone. Plays are differentiated on the basis of depositional style, including cap rock, aggradational, progradational, and submarine fan.

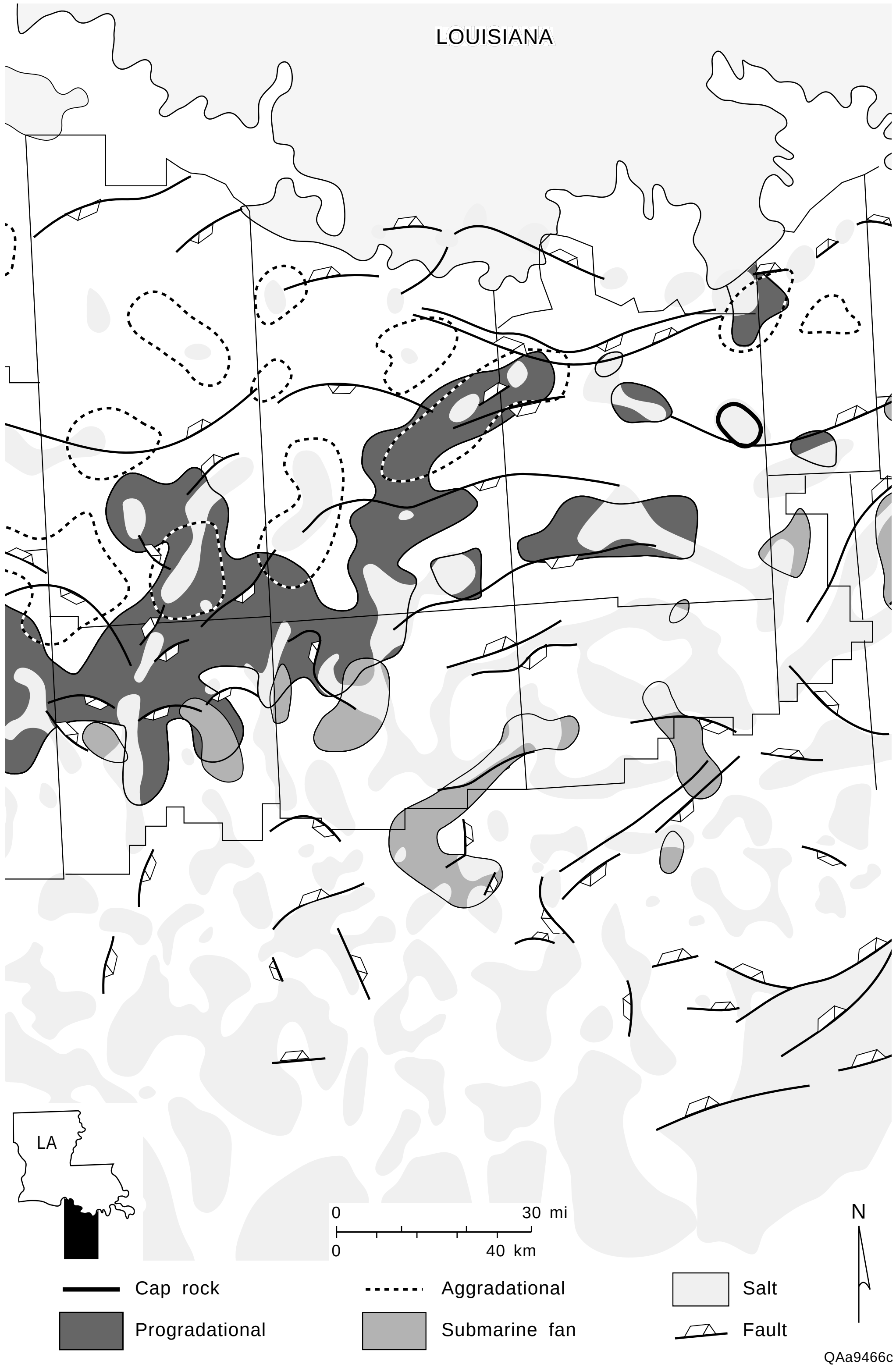


Figure 6. Map showing the relationship between plays for middle Pleistocene chronozone and structural features.

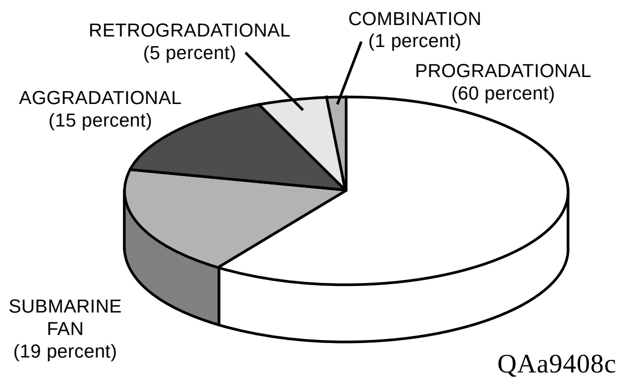


Figure 7. Proportional distribution of recoverable in-place hydrocarbons in the Federal OCS. Progradational plays contain the most resources (60 percent), which are followed by submarine-fan plays (19 percent), aggradational plays (15 percent), retrogradational plays (5 percent), and combination plays (1 percent).

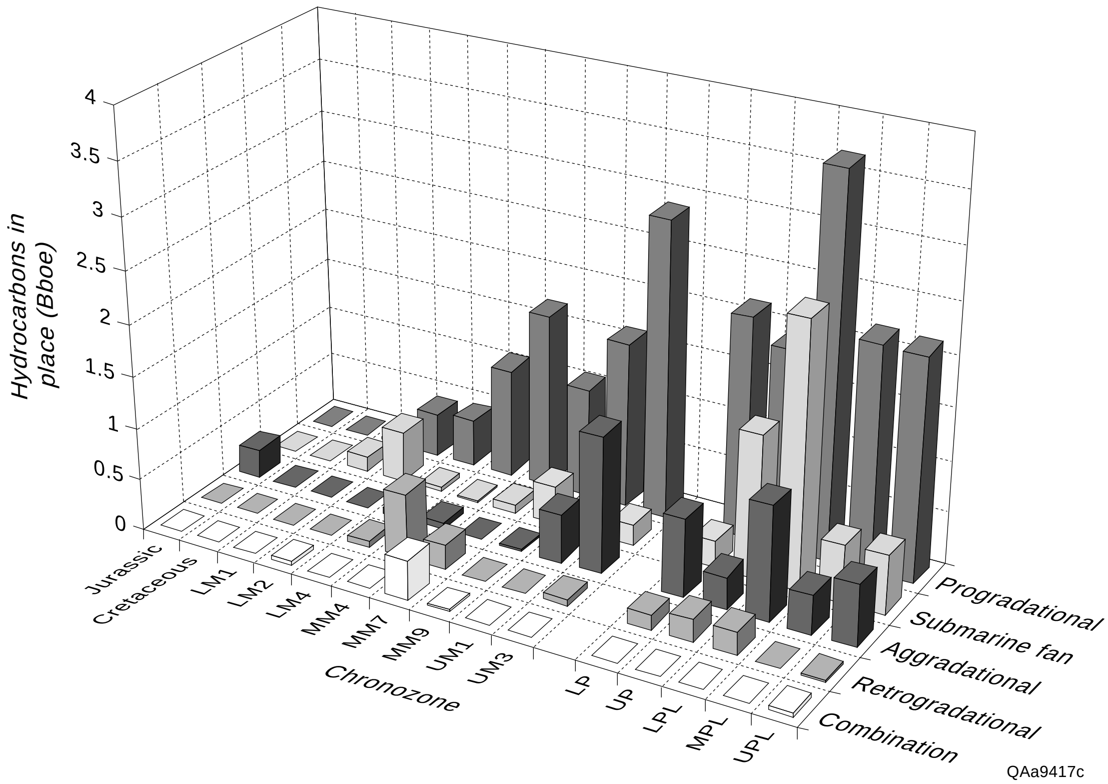
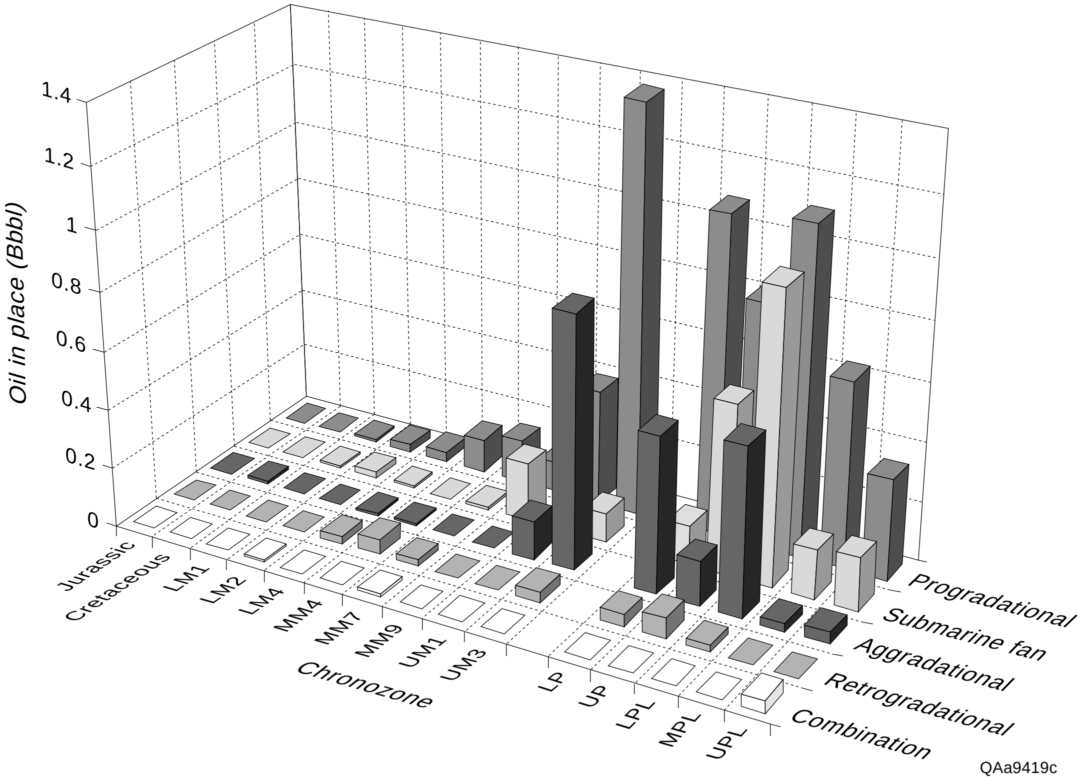


Figure 8. Producible in-place hydrocarbons (billion barrels of oil equivalent) in the Federal OCS. Chart illustrates resource distribution by depositional style for each chronozone.

a)



b)

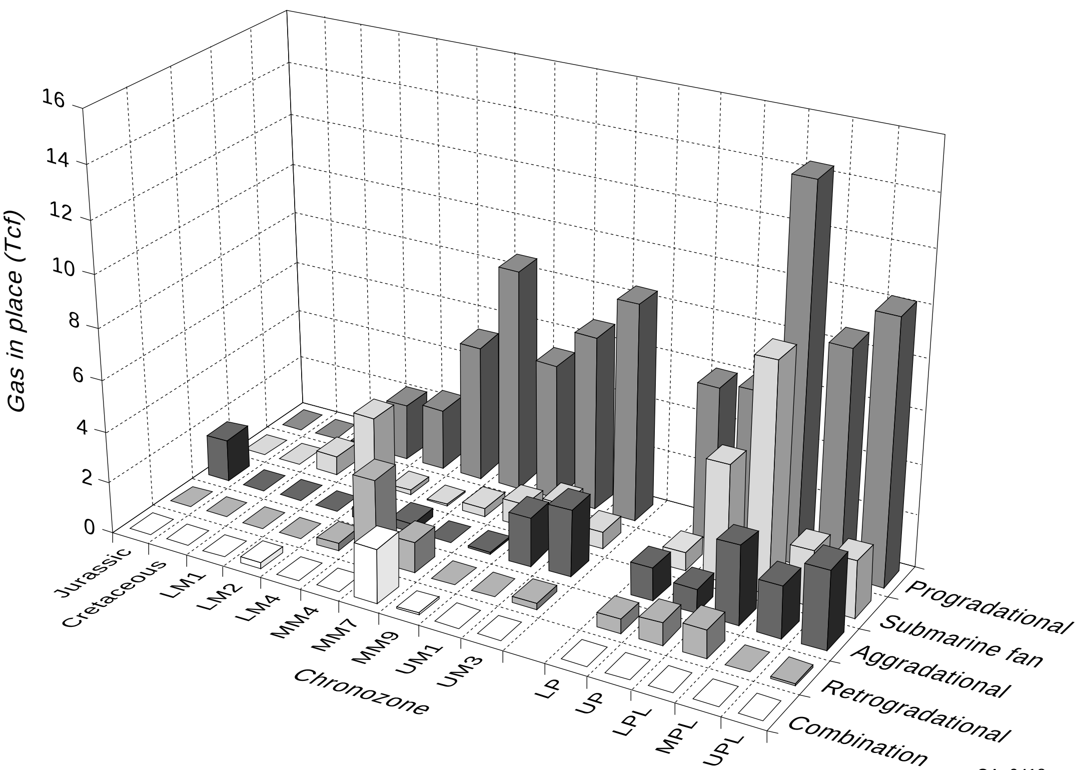


Figure 9. Producible in-place oil (a) (billion barrels) and gas (b) (trillion cubic feet) in the Federal OCS. Chart illustrates resource distribution by depositional style for each chronozone.

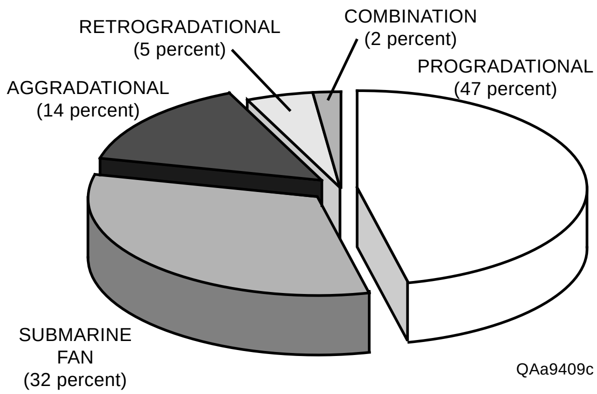
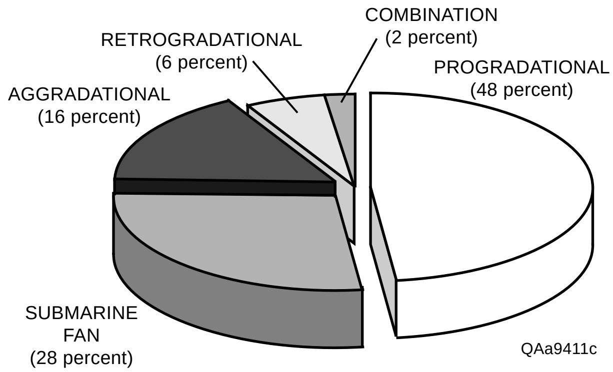


Figure 10. Proportional distribution of hydrocarbon reserves in the Federal OCS. Progradational plays contain the most reserves (47 percent), followed by submarine-fan plays (32 percent), aggradational plays (14 percent), retrogradational plays (5 percent), and combination plays (2 percent).

a)



b)

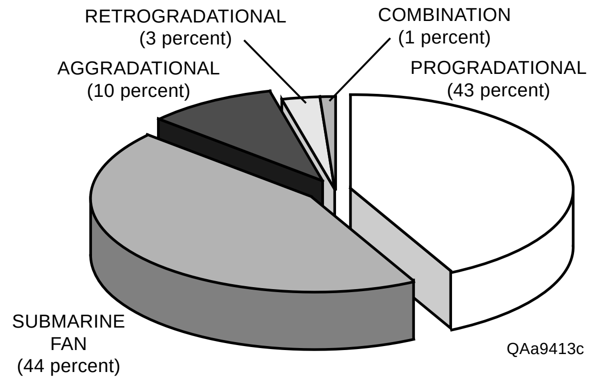


Figure 11. Proportional distribution of oil (a) and gas (b) reserves in the Federal OCS. The shift in distribution of reserves from progradational plays to submarine-fan plays is noteworthy. Submarine-fan plays contain the most oil reserves (44 percent) and are followed by progradational plays (43 percent), aggradational plays (10 percent), retrogradational plays (3 percent), and combination plays (1 percent).

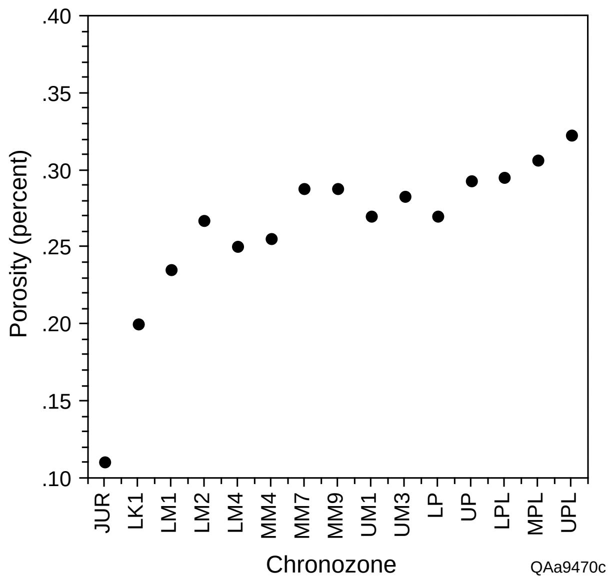


Figure 12. Graph of play-average porosity for all plays in a chronozone shows a systematic increase with decreasing age.

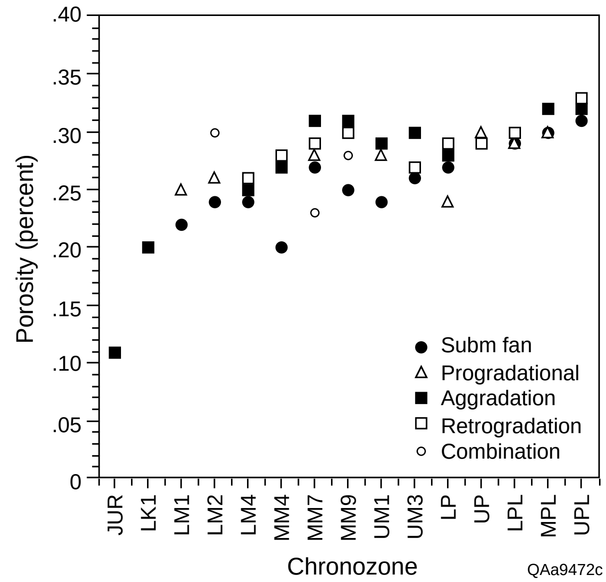


Figure 13. Graph of play-average porosity for all plays and depositional style for all chronozones. The play-average porosity for submarine plays (26 percent) is significantly lower than that for aggradational (28 percent), retrogradational (28 percent), and progradational (29 percent) plays.

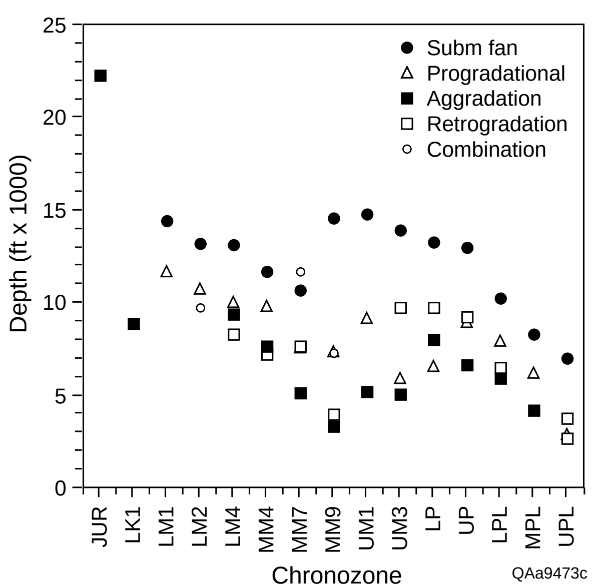


Figure 14. Graph of depth for all plays and depositional style for all chronozones. The depth trend illustrates a depth separation of 1,200 m (4,000 ft) to 3,050 m (10,000 ft) between aggradational and submarine-fan plays. A sudden increase in accommodation space occurred during the middle Miocene chronozone.